

## **SELF TRACKING, WIDE ANGLE SOLAR CONCENTRATORS**

### **RELATED APPLICATIONS**

This application is a continuation in part of U.S. Application No. 10/198,385,  
5 filed July 18, 2002, (issued as U.S. Patent No. 6,700,055), which is a continuation of  
International Application No. PCT/US01/01755 filed January 19, 2001, which claims  
priority to U.S. Provisional Application No. 60/177,124 filed January 20, 2000, the  
disclosures of which are all incorporated herein by reference.

### **BACKGROUND OF THE INVENTION**

#### 10 **1. Technical Field**

The present disclosure relates generally to solar concentrators, and more  
particularly to a wide angle, self tracking solar concentrator.

#### **2. Description of the Related Art**

Solar concentrators collect sunlight over some area and direct the sunlight onto a  
15 (photovoltaic) solar cell of much smaller area. In this way, the optical power incident on  
a relatively large area is collected and converted to electrical power, at some efficiency,  
by a relatively small solar cell. The solar cell is typically based on crystalline silicon or  
gallium-arsenide. One reason for employing a concentrator is that solar cells are  
currently the most expensive component of photovoltaic arrays on a per unit area basis.  
20 Another reason is that photovoltaic materials are more efficient at higher power levels  
than that of ordinary sunlight.

Typical prior art solar concentrators employ a Fresnel lens to focus incident sunlight onto the solar cell. If the Fresnel lens and solar cell are stationary as the sun moves overhead, the focal spot will move across and eventually off of the small solar cell. In other words, the field of view of the optical system is very limited. In order to  
5 compensate for this limitation, concentrator systems are typically designed to track the sun, i.e. the optic axis of the system is continuously or periodically mechanically adjusted to be directed at the sun throughout the day and year. However, such periodical mechanical adjustments require a relatively complex, costly structure. In addition, power is required to make the adjustments, thereby reducing the overall efficiency of the system.

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### **SUMMARY**

The present disclosure is directed to a self tracking solar concentration which employs at least one collector lens to at least partially focus incident sunlight onto at least one array of lens elements, such as, for example, a Fresnel lens array. Each element of  
15 the lens array is preferably smaller than the collector lens. As the sun moves overhead, the partially focused sunlight moves across each element of the lens array. For a particular angular position of the sun, a respective element of the lens array focuses the incident sunlight onto one edge of the solar cell. As the angular position of the sun changes, the focal spot moves across the surface of the solar cell and eventually off the  
20 opposite edge of the cell. As this occurs the partially focused beam moves across the element of the lens array and onto an adjacent element. This latter element of the lens array keeps the final focal spot on the surface of the solar cell for a contiguous range of angular motion of the sun. Thus, the solar concentrator described herein effectively

tracks the sun without requiring mechanical motion of the system and provides a significantly broader field of view than conventional solar concentrators. This broad field of view advantageously directs sunlight which is scattered or diffused before reaching the surface of the solar panel onto the solar cell. In the most direct implementations of the present invention, the field of view of the system is effectively divided into angular sectors each one of which employs one element of the lens array to keep the focused radiation on the surface of a solar cell for a range of angles. Ordinarily the system will be designed so that these angular ranges are contiguous in order to maximize the collection of both direct, scattered, and diffused sunlight.

10 In alternative embodiments, an array of collector lenses, an array of lens arrays and/or an array of solar cells is employed in the solar concentrator described herein.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

The features and advantages of the disclosed optical concentrator will become more readily apparent and may be better understood by referring to the following detailed descriptions of illustrative embodiments, taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic side view illustrating a solar concentrator in accordance with an embodiment of the present disclosure;

20 FIG. 2 is a schematic side view illustrating an alternative embodiment of the present disclosure which includes means for directing wide angle radiation onto the elements of the lens array which are closer to the center of the system than the directing means;

Fig. 3 is a schematic side view illustrating still another embodiment of the present disclosure which employs an array of solar cells; and

Fig. 4 is a top schematic view of a plurality of lens arrays arranged in side by side relation which can be used in alternate embodiments in place of single lens array 2.

5           Figure 5 illustrates a further embodiment of a solar collector in accordance with yet another aspect of this disclosure wherein a multiplicity of lenses are superimposed on the surface of a larger lens.

#### **DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

10           Turning now to the drawings, in which like reference numerals identify similar or identical elements throughout the several views, FIG. 1 illustrates, in a schematic side view, one embodiment a solar concentrator in accordance with the present disclosure. Housing “h” houses the components of the optical system and defines an opening “o” to receive incident sunlight. It should be understood that any support means (such as, for  
15           example, a framework, scaffolding, or housing) or combination of support means can be used to support the various components of the present solar concentrators. The choice of any particular support means or combination of support means will depend on the size and configuration of the solar concentrator. A collector lens 1, which in the preferred embodiment is a Fresnel lens, spans opening “o” and collects incident sunlight rays “r”  
20           and at least partially focuses the incident sunlight rays 4 onto part of one element 21 of lens array 2. As used herein, the term “array” includes both one and two dimensional arrays. Lens array 2 preferably is a Fresnel lens array. The focal plane of collector lens 1 may be on either side (e.g., above or below) lens array 2. Array 2, in turn, focuses the

emerging radiation or rays “e” from lens 1 onto the surface of solar cell 3. The function of the element 21 of array 2 is to keep the focal point of the radiation on the surface of the solar cell as the sun moves through a small predetermined angle of movement from east to west. Eventually, as the sun moves further, the partially focused beam moves onto the  
5 next adjacent element 20 of array 2. This element 20 of array 2 then directs the emerging rays “e” on a focal spot on the surface of the solar cell 3 for the next contiguous range of east-west angular positions of the sun. It should, of course be understood that whether the partially focused beam moves toward element 20 or 22 of array 2 depends on the orientation of the device relative to the movement of the sun. Each element of lens array  
10 2 keeps the focal spot on the surface of the solar cell 3 for one of a set of contiguous predetermined angular ranges of the position of the sun. Thus all, or substantially all, of the optical power incident on the lens 1 is focused into a single focal spot on the surface of the solar cell 3 for a wide range of angles as the east-west angular location of the sun varies.

15 In order to accommodate yearly, north-south, angular variations of the location of the sun, a number of Fresnel lens arrays arranged in side by side relation can be employed as shown in more detail in Fig. 4, described below.

FIG. 2 is a schematic drawing illustrating an alternative embodiment in accordance with the present disclosure which is a variation of the embodiment illustrated  
20 in FIG. 1. The new feature is the addition of directing means (e.g., mirrors, prisms, such as, for example, right angle prisms, etc.) 5 to re-direct very wide angle sunlight rays “w” towards the center of the system where it is more easily focused onto a solar cell 3 by an element, e.g., 22 of lens array 2. In some applications, improved performance can be

obtained by dividing collector lens **1** into a number of segments, employing array elements on array **2** which are smaller than the beam width, or employing more than one solar cell **3**.

FIG. **3** is a schematic drawing illustrating another embodiment in accordance with the present disclosure which consists of a first array of collector lenses **1**, e.g., Fresnel lenses, and a second array **2** of Fresnel lenses and an array of (photovoltaic) solar cells **3**. Sunlight is incident on the first array of lenses **1**. Array **1** consists of one or more elements (**11**, **11a**, **11b**) which are optically similar or even identical. The optical behavior of one element **11** of the first array is illustrated in the figure. The field of view is divided into a number of angular sectors, e.g. **40**, **41**, **42**, **43**, **44**, **45**. This system is symmetric across the vertical center line of the figure. Sunlight in the angular sector **40**, for example, incident on the array element **11** of the first lens array **1** is partially focused onto the array element **20** of the second Fresnel lens array **2**. The width of the partially focused beam on the second Fresnel array **2** may be greater than, less than or equal to the width of each element of array **2**. Also the focal plane of Fresnel lens element **11** may be either above or below the second lens array **2**. Array element **20** focuses the partially focused incident radiation onto solar cell **30**. Similarly sunlight in the angular sector **41** incident on the array element **11** of the first Fresnel lens **1** is partially focused onto the array element **21** of the second Fresnel lens array **2**. This array element **21** also focuses the partially focused radiation onto the solar cell **30**. Radiation in the angular sectors **42** and **43** incident on the array element **11** of the first Fresnel lens array **1** is partially focused onto elements **22** and **23**, respectively of the second Fresnel lens array **2** and then onto the solar cell **31**. Finally, radiation in the angular sectors **44**, and **45** incident on the

array sector 11 of the first Fresnel lens array 1 is partially focused onto the elements 24 and 25 of the second Fresnel lens array 2. These elements in turn focus the partially focused radiation onto solar cell 32.

The number, size, location, and optical characteristics of the elements of lens array 2 as well as the number of elements in the solar cell array 3 corresponding to one element of the lens array 1 can be optimized for cost, optical and electrical efficiency, angular field of view, and other parameters of the system. Further, the configuration of Fig. 3 can optionally be supplemented with directing means (e.g., mirrors, prisms, etc.) as in FIG. 2. As noted previously, yearly north-south variations in the angular position of the sun can be accommodated by employing multiple rows of Fresnel lens arrays of type 2 as disclosed schematically in Fig. 4. Additionally, while FIG. 3 illustrates a one dimensional array, the same principles and constructions may be applied to realize a two dimensional array.

Fig. 4 is a schematic view depicting an embodiment that includes multiple lens arrays 2a-2d in side by side relation. The field of view of each individual row is a fixed north-south angular sector. By employing a number of rows each with a different fixed north-south angular field of view, the north-south field of view of the total system can be made equal to the yearly, apparent north-south excursions of the sun or even greater.

Computer modeling was used to evaluate the effect of variations in the distance (d) between the collector lens 1 and the lens array 2. (See Fig. 1) It is contemplated that the distance d can be adjusted to optimize the performance of the system. Quite surprisingly, the computer model showed that the system worked well even when the distance between the collector lens and the lens array approached or was equal to zero.

Thus, in another aspect the present disclosure contemplates a solar collector that includes a unique optical element having both the collector lens function and the lens array function combined into a single lens surface as illustrated in Figure 5. In one such embodiment, the top surface of optical element 100 has a multiplicity of lenses 102 superimposed on the surface of a larger lens 105. The surface of lens 105 is shown as a dashed line in Fig. 5. Techniques for preparing optical element 100 are within the purview of one skilled in the art. Although a single optical element 100 is shown in Fig. 5, it should be understood that an array of such optical elements can be employed. This compound lens 100 partially focuses the incident solar radiation onto the photovoltaic material of a solar cell 110. The optical element 100 can be oriented as shown in Fig. 5 or inverted with a flat surface on top of the system. It is further contemplated that lenses 102 or lenses 105 or both can be Fresnel lenses.

As will be understood by those skilled in the art, various modifications in form and detail may be made therein without departing from the scope and spirit of the present invention. For example, non-Fresnel lenses may be used in some locations, movable or adjustable lenses, mirrors, and prisms, with appropriate structure or control mechanisms, may be employed as the internally disposed means for directing received radiation in a small angular range onto a solar cell. Further, it is not necessary that all or any of the arrays employ elements which are all of the same size. The optimum configuration may contain lens arrays which are significantly non-periodic in size and/or other characteristics. Clearly each element must have different optical characteristics. In one embodiment the second lens does not have separate elements but rather a continuous variation in optical properties. This may be approximated by a Fresnel lens. Further, any



or all of the Fresnel lenses may be replaced by non-Fresnel lenses, microlenses, or optical elements designed on the basis of the principles of diffractive optics. Accordingly, modifications such as those suggested above, but not limited thereto, are to be considered within the scope of the invention.

5           Ordinarily, but not necessarily, the system disclosed herein will be incorporated into a framework with a glass cover which may or may not have an associated tracking system and inverter. Some designs will require a cooling system for the solar cells in order to keep their operating temperature in the optimum range of electrical efficiency. Finally, it is possible to replace the solar cells by thermally absorbing material to generate  
10   heat rather than electrical power. The thermal energy can then be used directly for heating applications or to generate electrical power.

          Furthermore, multiple solar concentrators in accordance with the present disclosure can be combined into a one or two dimensional array to form solar modules, panels and/or arrays.

15           While the above description contains many specifics, these specifics should not be construed as limitations on the scope of the disclosure, but merely as exemplifications of preferred embodiments thereof. Those skilled in the art will envision other modifications within the scope and spirit of the claims appended hereto.